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Interaction of Seawalls and Beaches: Eight Years of Field Monitoring, Monterey Bay, California

By Gary B. Griggs, James F. Tait, Laura J. Moore, Katie Scott,
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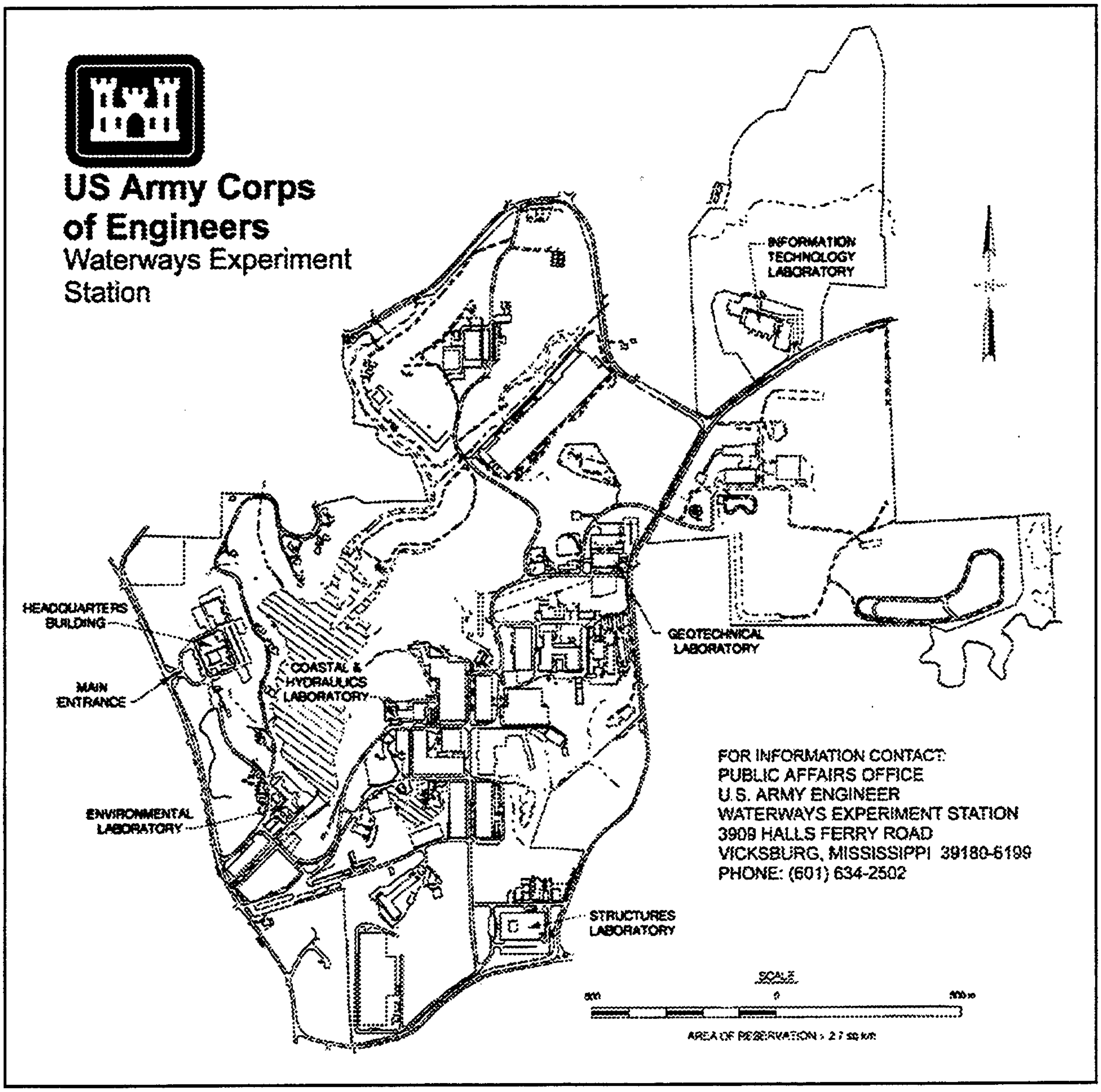

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Preface

The study summarized in this report was authorized by Headquarters, U.S. Army Corps of Engineers (HQUSACE). Research was conducted under Work Units 32535, "Engineering Performance of Coastal Structures," and 32747, "Impacts of Coastal Armoring on Beaches," Ms. Cheryl E. Pollock, Principal Investigator. Funds were provided through the Coastal Structures and Evaluation Branch (CSEB), Engineering Development Division (EDD), Coastal and Hydraulics Laboratory (CHL), and U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS. The CHL was formed in October 1996 with the merger of the WES Coastal Engineering Research Center and Hydraulics Laboratory. Dr. James R. Houston is the Director of the CHL and Messrs. Richard A. Sager and Charles C. Calhoun, Jr., are Assistant Directors. HQUSACE Technical Monitors were Messrs. John H. Lockhart, Jr.; John G. Housley; Charles B. Chestnut; and Barry W. Holliday.

Work was performed under the general supervisory direction of Dr. Yen-hsi Chu, Chief, Engineering Applications Unit, CSEB; Ms. Joan Pope, Chief, CSEB; Mr. Thomas W. Richardson, Chief, EDD; and Ms. Carolyn M. Holmes, Program Manager, CHL.

This report was prepared by Drs. Gary B. Griggs and James F. Tait and Mses. Laura J. Moore, Katie Scott, Wendy Corona, and Deborah Pembrook, Institute of Marine Sciences and Department of Earth Sciences, University of California, Santa Cruz.

The authors are particularly grateful to Drs. Nicholas C. Kraus and Yen-hsi Chu, and Mses. Joan Pope, Julie Rosati, and Cheryl Pollock, all of CHL, for their continued support over the 8-year period of this study. The authors also acknowledge the assistance of numerous graduate and undergraduate students who served as field assistants during winter and summer months alike, risking life and limb to collect the data that have gone into this study.

COL Bruce K. Howard, was Commander of WES during the publication of this report. Dr. Robert W. Whalin was Director of WES.

1 Introduction

Increasing development along much of the nation's receding shoreline, combined with a slow but continuous sea level rise, has produced a coastal crisis of increasing proportions. Even over the short term, there are fluctuations related to meteorological phenomena, e.g., shifts in the mean jet stream path and the El Niño-Southern Oscillation mechanism, that can cause rise or fall of mean sea level by 15-30 cm over a few years (National Academy of Sciences/National Research Council 1987). During the last major El Niño event in 1982-83, for example, the California coast experienced over $100 million in oceanfront storm damage due to a combination of elevated sea levels and storm wave activity. California is the nation's most populous state with 32 million people, 80 percent of whom live within 50 km of the coastline. Despite the storm damage of recent years, and the fact that 86 percent, or 1,520 km of California's 1,760 km of shoreline is eroding (Griggs and Savoy 1985), many people still desire to live virtually at the water's edge.

To date, there have been three basic choices for those communities or areas threatened with storm wave impact and shoreline recession:

a. Armoring: the emplacement of hard protection structures.

b. Nourishment: widening the beach with imported sand.

c. Retreat: relocate buildings away from the beach.

Whether to armor, nourish, or retreat is a site-specific issue and depends on several factors including the future sea level rise rate, the particular geologic setting, and local shoreline erosion rates. State or local politics and the economics of the alternative approaches to dealing with shoreline erosion are also important considerations. Over the past several decades, the most common approach to protecting either private or public oceanfront property along the coastline of the United States has been the construction of some type of protective structure, whether riprap, revetments, or seawalls. To date, over 200 km or 12 percent of the coast of California has been armored, much of this during the past 10 years (Griggs, Pepper, and Jordan 1992). At present costs of $3,000 to $9,000/m or $1.5 million-$9 million/km, this represents an enormous investment.

Historically, seawalls have been built to protect buildings and not beaches (Pilkey 1988). Because seawalls have been built at locations where shoreline recession or beach erosion is already evident, a connection has often been made between the two. As a result, the question has been asked: Do seawalls *cause* beach erosion? This question is now a concern to coastal engineers and geologists, as well as planners who must make decisions as to whether a proposed protective structure should be constructed. While the issue of impacts remains unsolved, planners and decision makers are becoming more hesitant to grant permits or authorize money for structures.

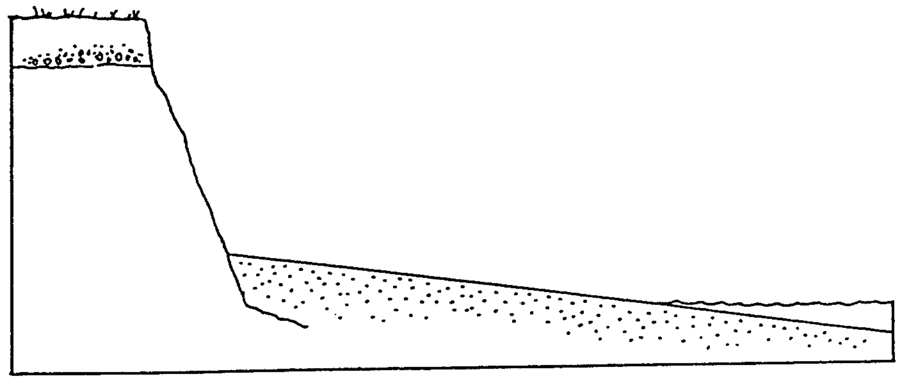
Any large engineering structure placed on a beach is going to interact to some degree with the physical processes operating in this energetic environment. Without question, construction of numerous jetties and breakwaters along the Atlantic, Gulf, and Pacific coastlines of the United States has produced significant shoreline change. The very reason for building these structures is to alter the physical processes, such that protected and stabilized channel entrances or safe harbors were created. Riprap revetments and seawalls are similarly built to alter or mitigate wave impact on the shoreline.

One approach to resolving the complex and often emotional issue of the potential effects of these hard structures is to break down the problem into manageable components. Pilkey and Wright (1988) list three different potential impacts or effects of armoring the shoreline, each of which will be discussed.

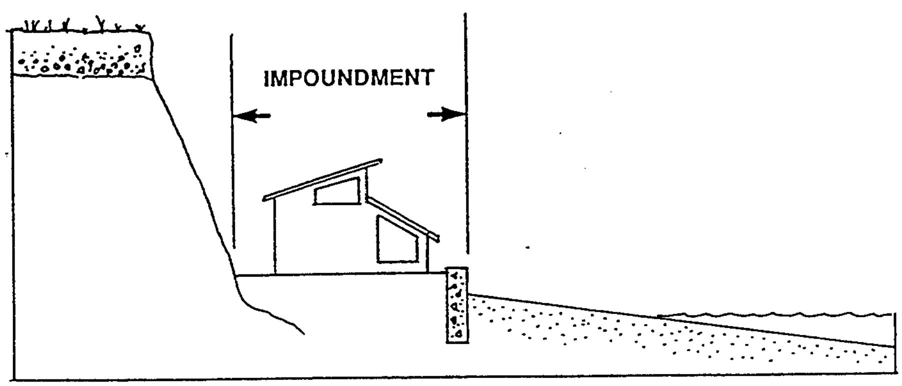
Impoundment or Placement Loss

This effect is the most straightforward and predictable. When a structure is built seaward of the base of the bluff, cliff, or dune, well out on the beach profile, a given amount of beach is covered (Figure 1). Thus the effect is immediate beach loss, the extent of the loss being a function of how far seaward and alongshore the structure extends. Along the margin of northern Monterey Bay, CA, for example, seawalls were built 35 to 75 m seaward of the base of the bluff in order to allow homes to be built on the back beach. As a result, in this location, 35 to 75 m of beach was permanently lost along 2 km of coastline.

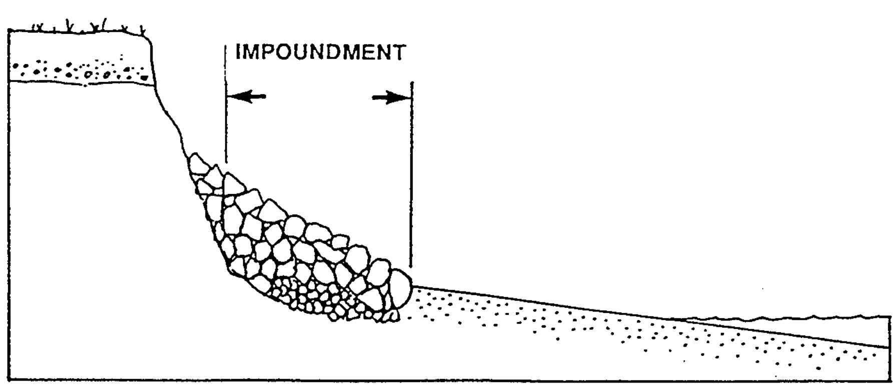
When a vertical seawall is built against the base of a bluff or dune, however, there is essentially no placement loss. On the other hand, where a revetment is constructed to protect a bluff, it may reach a height of 6 m or more, and extend seaward at a 1.5:1 or 2:1 slope, thus displacing or covering 10 to 15 m of beach (Figure 1). Placement loss can easily be determined for any proposed revetment if the cross-sectional and alongshore dimensions are known.



a. Beach with no coastal protection structures



b. Beach impoundment due to construction of seawall and home



c. Beach impoundment due to construction of revetment

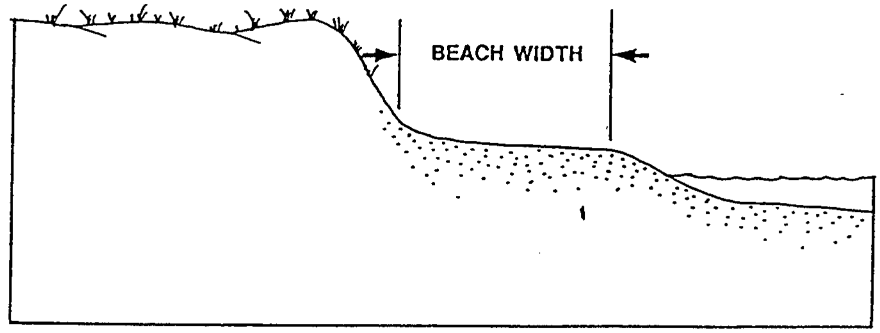
Figure 1. Examples of beach loss through placement of protective structures

Passive Erosion

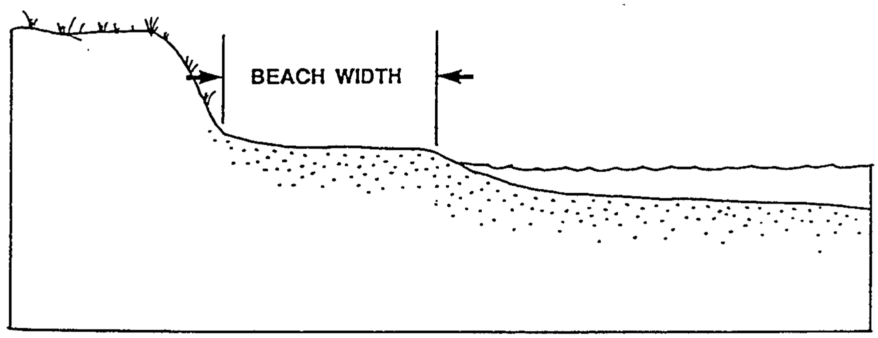
Whenever a hard structure is built along a shoreline undergoing long-term net erosion, the shoreline will eventually migrate landward beyond the structure (Figure 2). The effect of this migration will be the gradual loss of beach in front of the seawall or revetment as the water deepens and the shoreface profile moves landward. This process is designated as passive erosion and appears to be the process which has been documented along many of the barrier islands of the Atlantic coast. As barrier island shorelines erode and migrate, threatening homes and property, seawalls are often constructed for protection. As landward migration of the unprotected portions of the islands continues, in part due to sea level rise, the beach profile also migrates landward, resulting in beach loss in those locations where the shoreline has been fixed by a hard structure (Tait and Griggs 1990). This process of passive erosion appears to be a generally agreed upon result of fixing the position of the shoreline on an otherwise eroding stretch of coast, and is independent of the type of seawall constructed.

Active Erosion

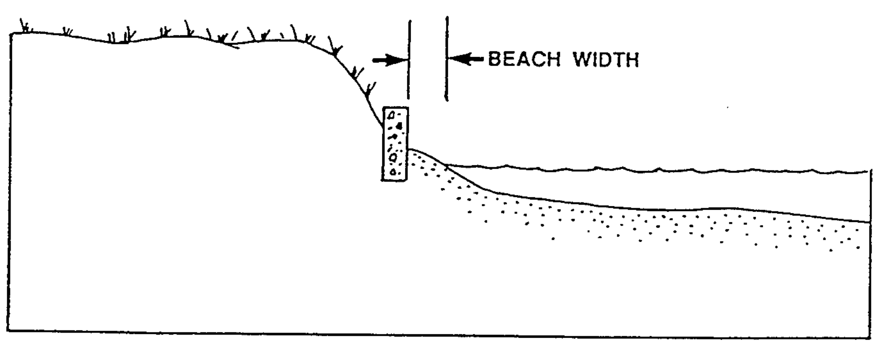
The ability or potential for a seawall or revetment to induce or accelerate erosion has, in the authors' view, been the source of most of the controversy over the past decade regarding the impacts of seawalls on beaches. Although different scientific opinions have been put forward regarding the impacts of these structures on adjacent beaches, there has, until recently, been a lack of field data with which to resolve the conflicting claims.



a. Initial shoreline profile showing beach width



b. Shoreline profile after sea level rise and associated dune or bluff erosion. Although shoreline has migrated landward, beach width remains the same



c. Shoreline profile following sea level rise where seawall has fixed shoreline position. Note reduced beach width

Figure 2. Example of beach loss through passive erosion following placement of a seawall

2 Seawall/Beach Interaction

In an effort to resolve the issues of impacts due to active erosion, a program of field monitoring was initiated in northern Monterey Bay in 1986 with funding from the Engineering Performance of Coastal Structures Research Unit of the Coastal Engineering Research Center at the U.S. Army Engineer Waterways Experiment Station. Beach profiles were surveyed at several different seawalls as well as at adjacent control (unarmored) beaches over a 7-year period. The objectives were to document the impacts of seawalls on the beach during the seasonal cycle and to identify any long-term trends. Efforts were also made to identify the physical processes which might be responsible for such impacts (Plant and Griggs 1992).

Specific questions to be addressed included:

a. How do beaches backed by seawalls change seasonally in response to changing wave climate compared to adjacent beaches without seawalls?

b. What bearing does seawall design have on beach response?

c. Does the position of a seawall on the beach profile exert any effect on the seasonal beach changes?

d. Do seawalls exert alongshore control on beach development, cross-shore control, or both?

e. Are there any long-term effects of seawalls on fronting or adjacent beaches?

Four monitoring sites were initially selected with the objectives of observing different types of protective structures at different locations on the beach profile. Both vertical impermeable seawalls and sloping permeable revetments were monitored. These structures varied in their location from the back of the beach at the base of the seacliff to as far as 75 m seaward on the beach profile. Following the first several years of monitoring, surveys were concentrated on a single curved-face concrete seawall with a riprap apron (the Aptos Seascape wall-Figure 3). Biweekly shore-normal surveys were carried out between October 1986 and May 1989, and in subsequent years, surveys have generally been conducted on a monthly basis throughout all but the summer

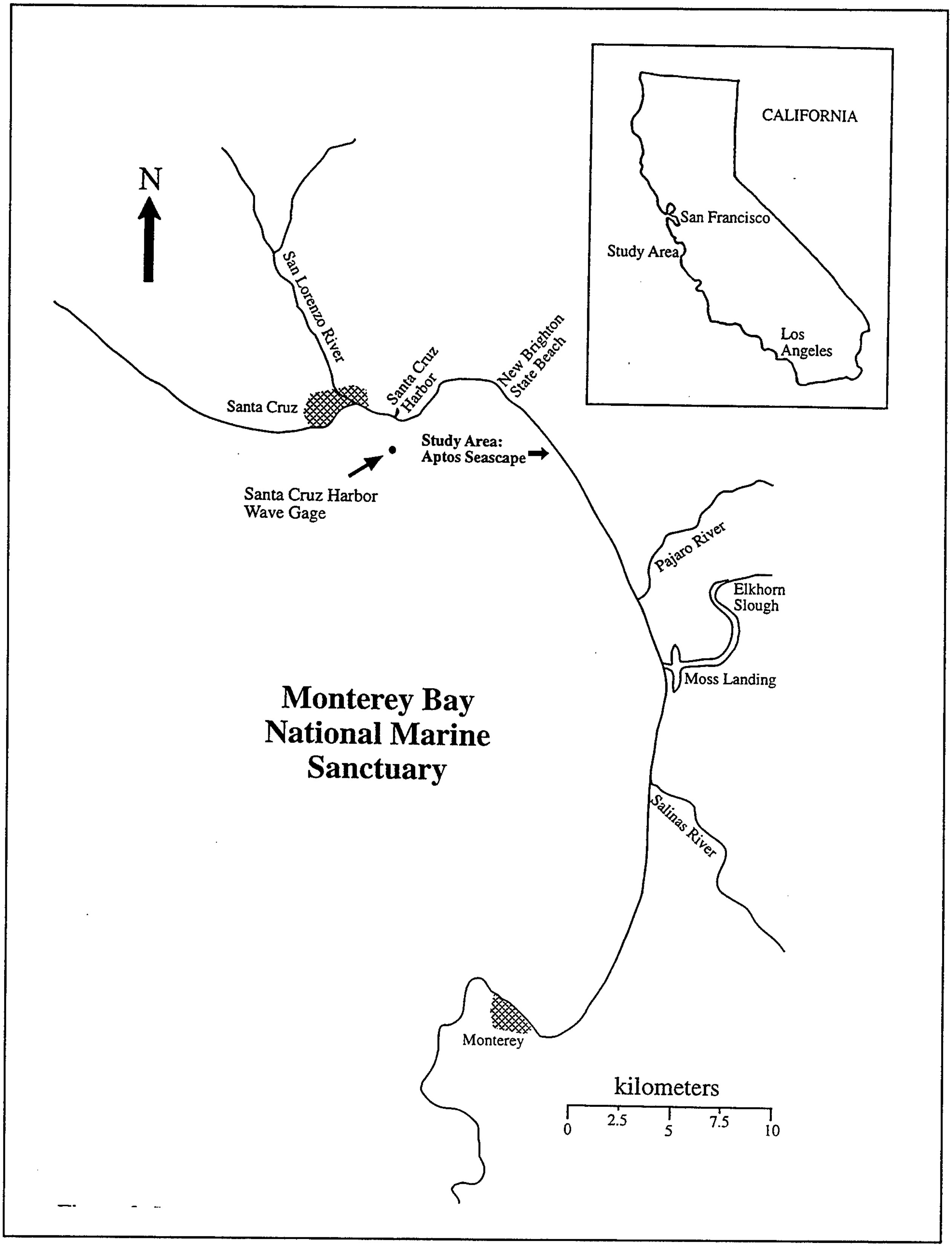


Figure 3. Location map for Monterey Bay

months when surveys were less frequent. Profiles extended from the seawall and adjacent, unprotected backbeach offshore to depths of -1 or -2 m (mean sea level (msl)). Profile lines were spaced at 60-m intervals alongshore (Figure 4) and were surveyed using a Leitz EDM (Electronic Distance Meter) and a pole-mounted prism reflector. Over the 7-year period, more than 2,000 profile lines were completed.

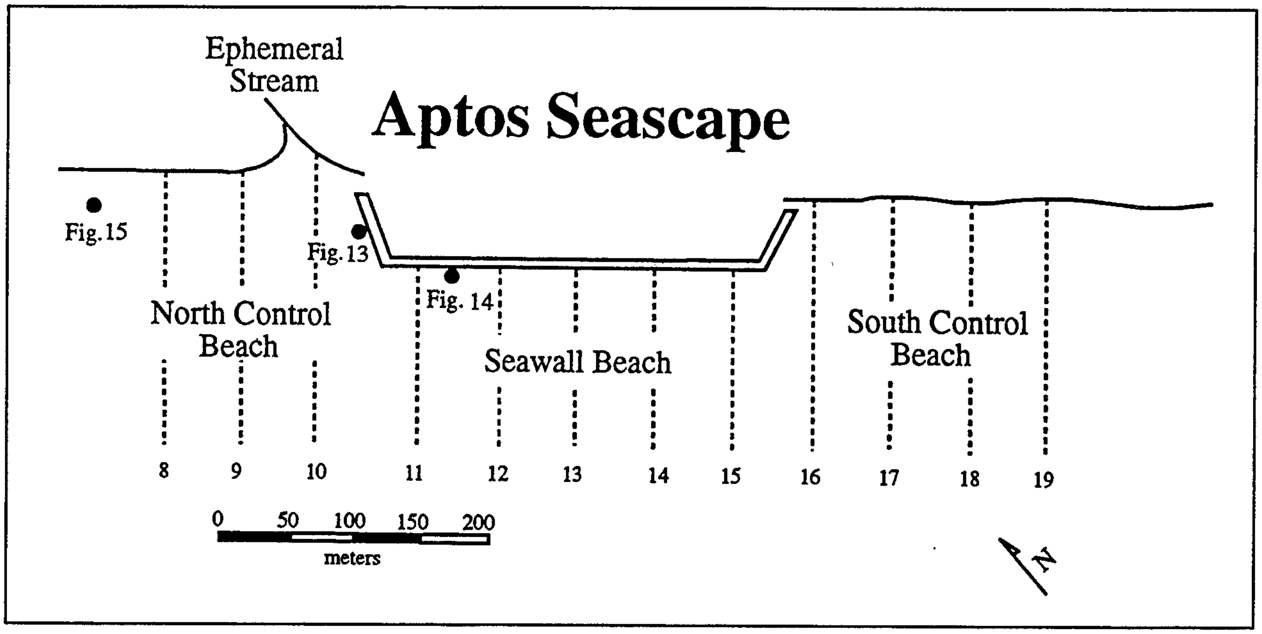


Figure 4. Location of survey profiles adjacent to the Aptos Seascape seawall

The coast of California forms a marked contrast to the Atlantic and Gulf coasts of the United States where the seawall impact debate has been focused. The study area in Monterey Bay consists of a cliffed coastline fronted by a broad equilibrium beach, which, while undergoing seasonal variations in width, is not undergoing net erosion. Thus the geomorphic and tectonic setting is strikingly different than the barrier island coastline of the Atlantic and Gulf coasts.

Of the three potential seawall impacts discussed earlier, two are relevant to the study area. Beach *impoundment* occurred at the time the seawalls and the developments they protect were constructed. *Passive erosion* is not an issue because there is no net shoreline recession in this region. *Active erosion* has been the focus of this investigation, and thus the results of this study are relevant to seawalls on any coastline.

Results of Beach Surveying-Seasonal Changes

A number of consistent seasonal beach changes related to the presence of seawalls and revetments were recognized during the first 7 years of surveying,

and are discussed below in chronological order (see Griggs and Tait (1988); Tait and Griggs (1990); Griggs, Tait, and Scott (1990); and Griggs et al. (1991) for additional data). In addition, the authors have compared profile changes over time to determine if any long-term effects or impacts are taking place.

Summer beach conditions

At the start of each season of monitoring (early fall) the beach at each of the survey sites has accreted to the point where the berm is well seaward of the seawall and there is no wave-seawall interaction. The summer berm is continuous alongshore with no deflection or differences in the vicinity of the seawall. Thus, although the summer berm varies somewhat in both its height and its cross-shore position from year to year, the beach/seawall system retains no "memory" of the previous winter's interactive morphology.

Erosion or retreat of summer berm

During the transition from summer to winter (reflective to dissipative) beach states, the berm in front of the seawall experiences greater erosion than the berm on adjacent control beaches. A flat winter profile is attained earlier in front of the seawall. Typical volumetric differences observed in the study period are on the order of 25 m^3/m of shoreline. The berm on the unprotected beach may be as far as 12 m seaward of the seawall position. The timing and extent of this accelerated berm erosion in front of the seawall is controlled by the width of the initial summer berm fronting the seawall and the winter wave climate. The berm is lost first from those seawalls that are closest to the surf zone. This accelerated berm removal may be due to one or a combination of the following mechanisms: (a) wave reflection from the seawalls and revetments at high tide, (b) increased suspension due to turbulence, and (c) elevated beach water table (Plant and Griggs 1992).

An issue of some controversy along many coastlines is whether permeable revetments produce less reflection and beach scour and are, therefore, preferable to impermeable revetments. Although several sites were studied where vertical impermeable concrete seawalls abut sloping permeable revetments, there was no consistent difference in the beach profiles at these sites over the years of monitoring. This indicates that under the wave conditions experienced, differences in permeability had no significant influence on berm erosion.

Winter or storm profile

As winter waves continue to erode both the seawall-backed beach and the unprotected beach, the berm on the unprotected beach retreats until it is landward of the seawall. Once this winter state has been attained, there are no

significant alongshore differences between the armored and unarmored beaches.

Another issue is whether wave-induced scour in front of a seawall produces a trough. In 7 years of surveying, the authors have never observed a scour trough directly fronting any of the seawalls studied. The possibility exists that an area of scour does develop immediately in front of a seawall during high tide and peak storm wave conditions, but does not persist long enough to be observed. If this is the case, then the impacts of such a process would appear to be insignificant.

End effects of seawalls

Direct wave reflection from the end sections of seawalls is commonly observed. As a result of this increased wave energy at the downcoast or downdrift ends of seawalls, an arcuate zone of localized scour typically develops in the winter months which extends downcoast from 50 to a maximum of 150 m. The downcoast extent of this impact appears to depend upon wave height and wave period, or the arrival of the next wave bore, which tends to override and dissipate the reflected wave, the end geometry of the structure, the angle of wave approach, and tidal stage.

Reconstruction of summer berm

With the change from winter to spring and summer wave conditions, the berm begins to rebuild, a process which begins in May and June and continues into July and August. Sequential biweekly surveys of this accretionary phase indicate that the berm on the unprotected beach advances seaward until it reaches the cross-shore position of the seawall, and then the berm in front of the seawall and adjacent beach advance together. It is interesting that the winter erosional phase of the seasonal beach cycle is influenced to some degree by the presence of the seawall but the summer accretionary phase is not. By late spring/early summer, a uniform alongshore berm crest exists well seaward of the seawalls.

Results of Beach Surveying-Long-Term Effects of Seawall/Beach Interactions

A 1- or 2-year study of seawall-beach interactions is inadequate to address the issue of any long-term impacts or trends. It is also difficult to know from a single year of monitoring whether the results are typical or unique to the wave and tidal conditions of that particular year. The 7-year survey record for Monterey Bay provides a substantial data set from which to assess the presence or absence of long-term trends.

Long-term trends were stastically analyzed by comparing a single transect in front of a seawall with a single transect on a nearby control beach. The profiles surveyed in the month of February at each transect were temporally averaged over the study period to give the average winter profile. The profiles surveyed in the month of June at each transect were temporally averaged to produce the average summer profile. Also, the cross-shore location of the mean sea level intercept at the two transects has been plotted as a function of time using profiles from every month (it should be noted that for some years, data for these profiles were not available).

Summer Profiles

Control beach (line 18-June)

The summer berm on the control beach built out slightly further seaward each successive year (Figure 5). The offshore profile also shows a general trend towards seaward displacement as well. Shoreline position is a parameter often used to quantify the magnitude of beach erosion or accretion. Analysis of profile data, rather than aerial photographs, allows the use of mean sea level, a more exact datum. During the period from 1987 to 1993, the mean sea level intercept of the June profile migrated approximately 23 m seaward. Drought conditions prevailed for the first 6 years of surveying and it is the authors' hypothesis that the indirect results of the drought, perhaps a combination of reduced winter wave energy or increased onshore transport of sand during spring and summer months, produced a wider but lower berm.

Seawall beach (line 13-June)

Beach profiles fronting the seawall indicate a progressive seaward migration between 1987 and 1993 similar to those on the control beach (Figure 6). The net displacement of the mean sea level intercept on the seawall-backed beach was approximately 27 m. This is certainly not consistent with the notion of net long-term beach erosion due to seawalls.

Winter Profiles

Control beach (line 18-February)

In contrast to the progressive shift of the summer profiles, the winter profiles on the control beach show relatively little change from year to year; each winter, with the exception of 1988, the berm is cut back to approximately the same position and elevation (Figure 7). No continuous trend of seaward migration of the msl intercept is observed. Its position oscillates through a horizontal range of about 15 m.

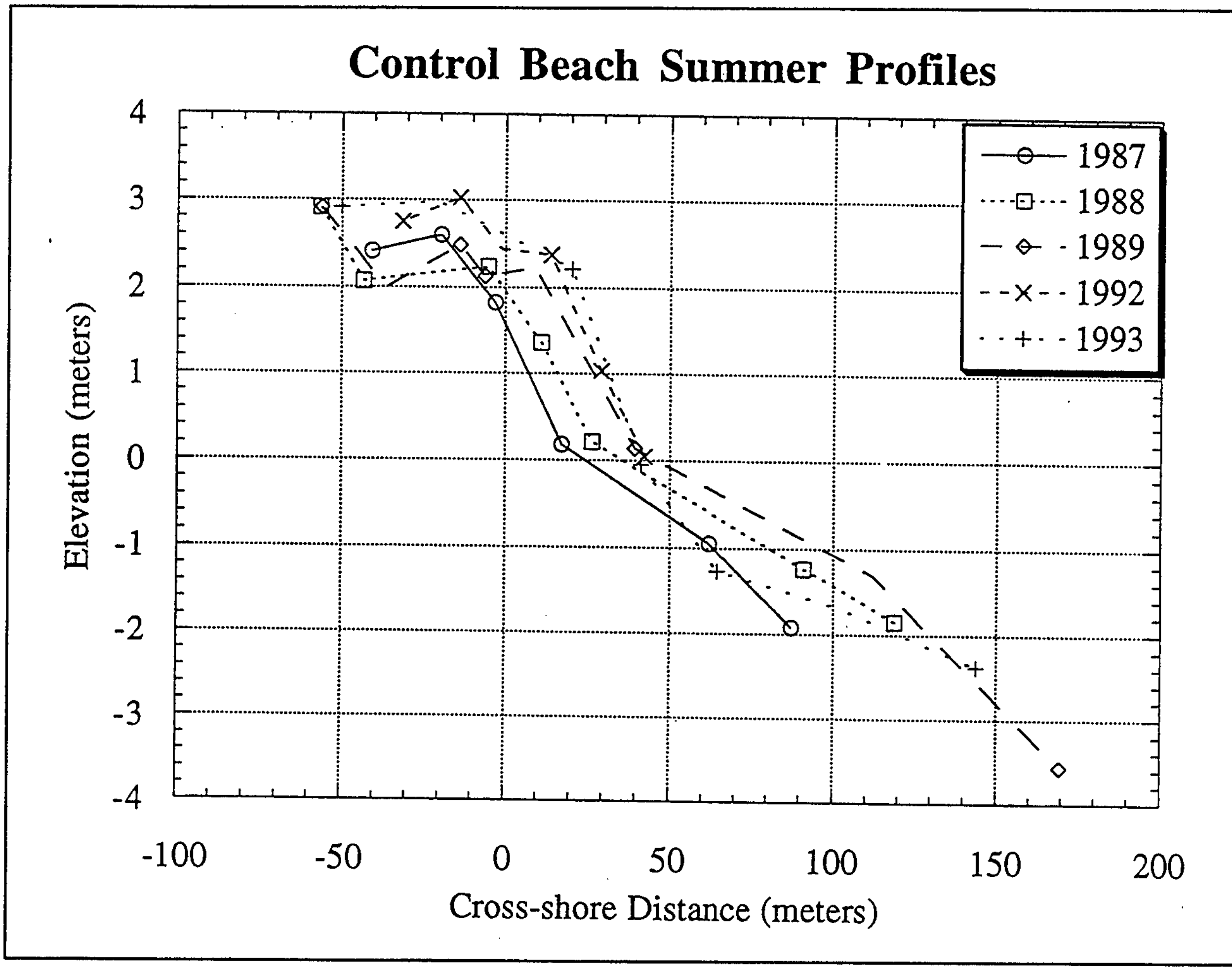


Figure 5. Summer profiles for line 18 on control beach between 1987 and 1993

Seawall beach (line 13-February)

The msl intercept on the seawall beach also oscillates over the study period, not showing a clear trend. The range of oscillation, approximately 8 m, is even smaller than that of the control beach. Since the landward limit of winter beach erosion is fixed at the position of the seawall, the winter profiles of the beach fronting the seawall are almost identical throughout the study period (Figure 8). The winter beach elevation varies by only 30 cm to 60 cm from year to year across the nearshore zone and beach face.

Mean sea level intercept

To compare the long-term behavior of the seawall-backed beach to that of the control beach, the cross-shore position of the mean sea level intercept for each was plotted as a function of time (Figure 9). This is essentially a continuous measure of beach width throughout the period of study. The progressive

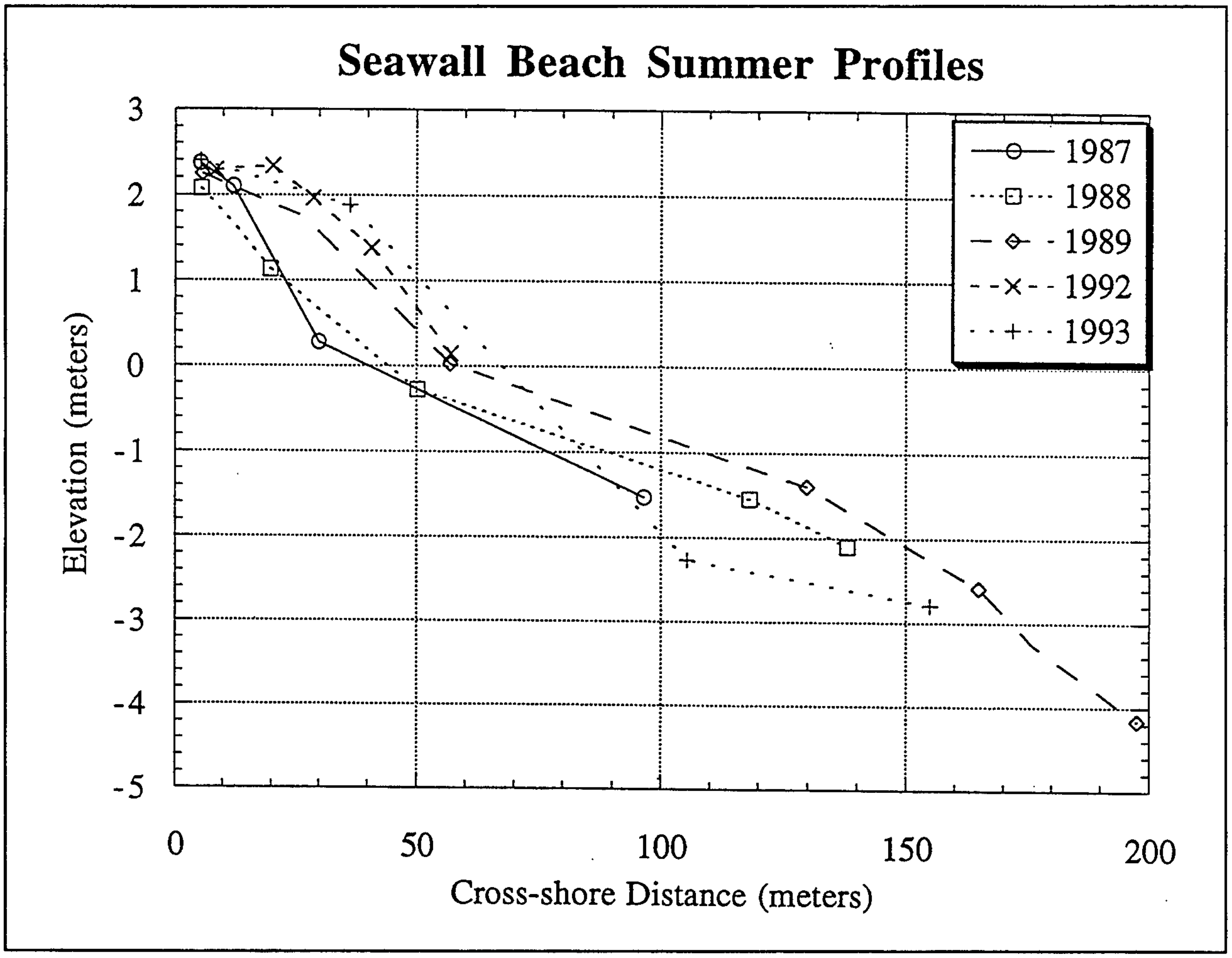


Figure 6. Summer profiles for line 13 on seawall beach between 1987 and 1993

widening of the beach throughout the drought period is shown by the slope of the best-fit lines. The offset in the two curves is an artifact of the curvature of the shoreline relative to the seawall. The objective in this analysis is to separate the influence of the seawall from other possible long-term trends. A positive slope represents a long-term accretionary trend and a negative slope would indicate an erosional trend. If the two curves have the same slope, i.e., are parallel, this suggests that the seawall has no long-term impact on beach width. Although there is considerable scatter in the data, due to the seasonal variation in beach width, the slopes of the best-fit lines are virtually identical. The migration rate for the mean sea level intercept at the seawall-backed beach is 2.43 m/year and the migration rate for the control beach is 2.44 m/year.

Comparison of summer seawall and control beaches

In order to develop a long-term comparison, all of the summer seawall profiles (June-line 13) and the summer control beach profiles (June-line 18) were combined into two composite or average profiles (Figure 10). Offset due

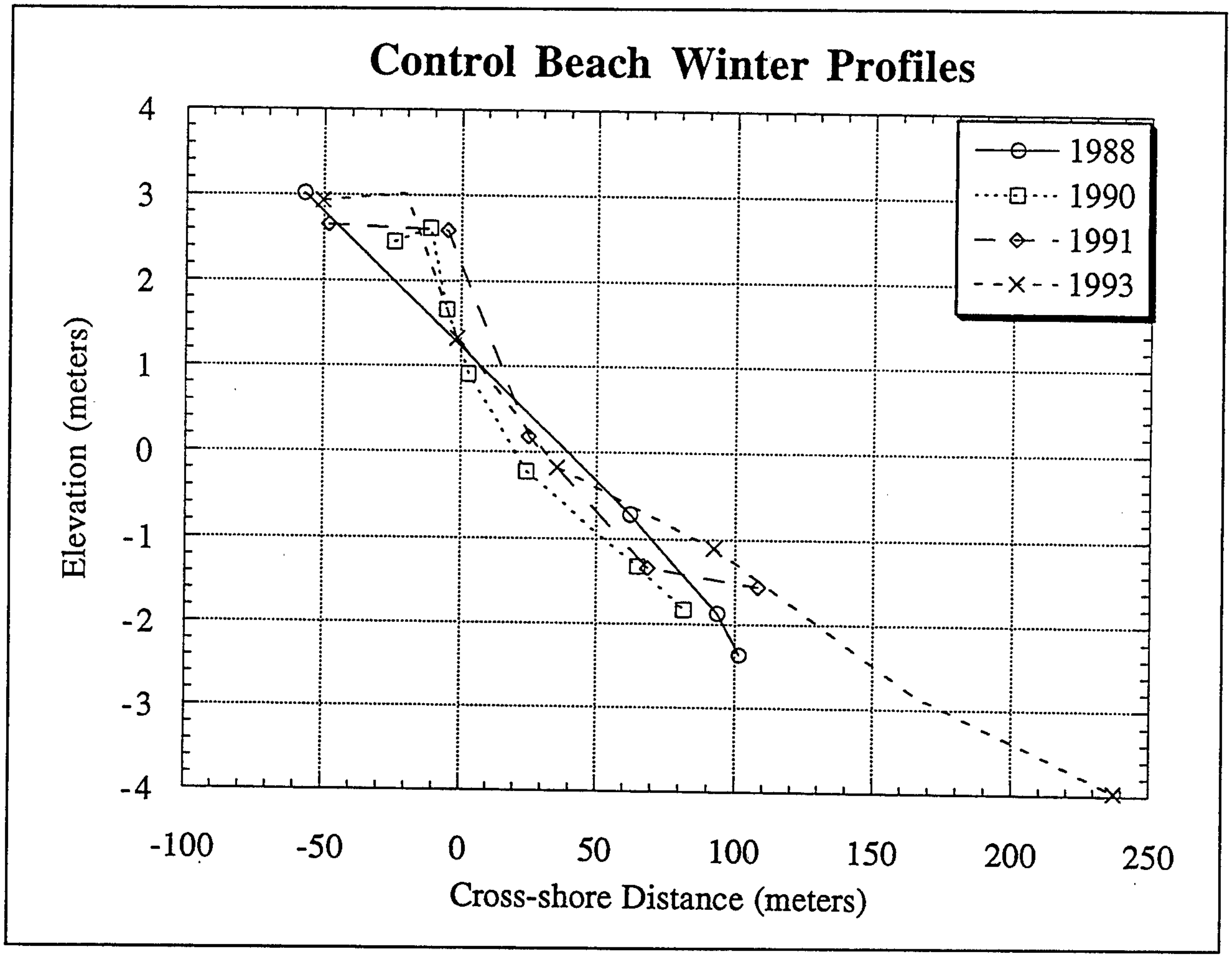


Figure 7. Winter profiles for line 18 on control beach between 1987 and 1993

to the shoreline curvature has also been removed so the profiles can be directly compared. Although there are some slight differences, the two composite profiles are practically identical. This indicates that, despite any impacts during the winter months, the summer beach retains no memory of the seawall's presence.

Comparison of winter seawall and control beaches

Waves impact the Aptos Seascape seawall every winter. If there were any significant or persistent impact or effect of the seawall on the winter beach, it should be evident on these averaged profiles of the seawall and control beach profiles from mid-winter (February) throughout the 6 years plotted (Figure 11). The profiles are virtually identical, however, and show no significant difference or effects during the winter months of the study period. It is worth noting that because these profiles were taken from the latter portion of the winter, they do not reflect the initial accelerated berm loss in front of the seawall discussed under seasonal changes.

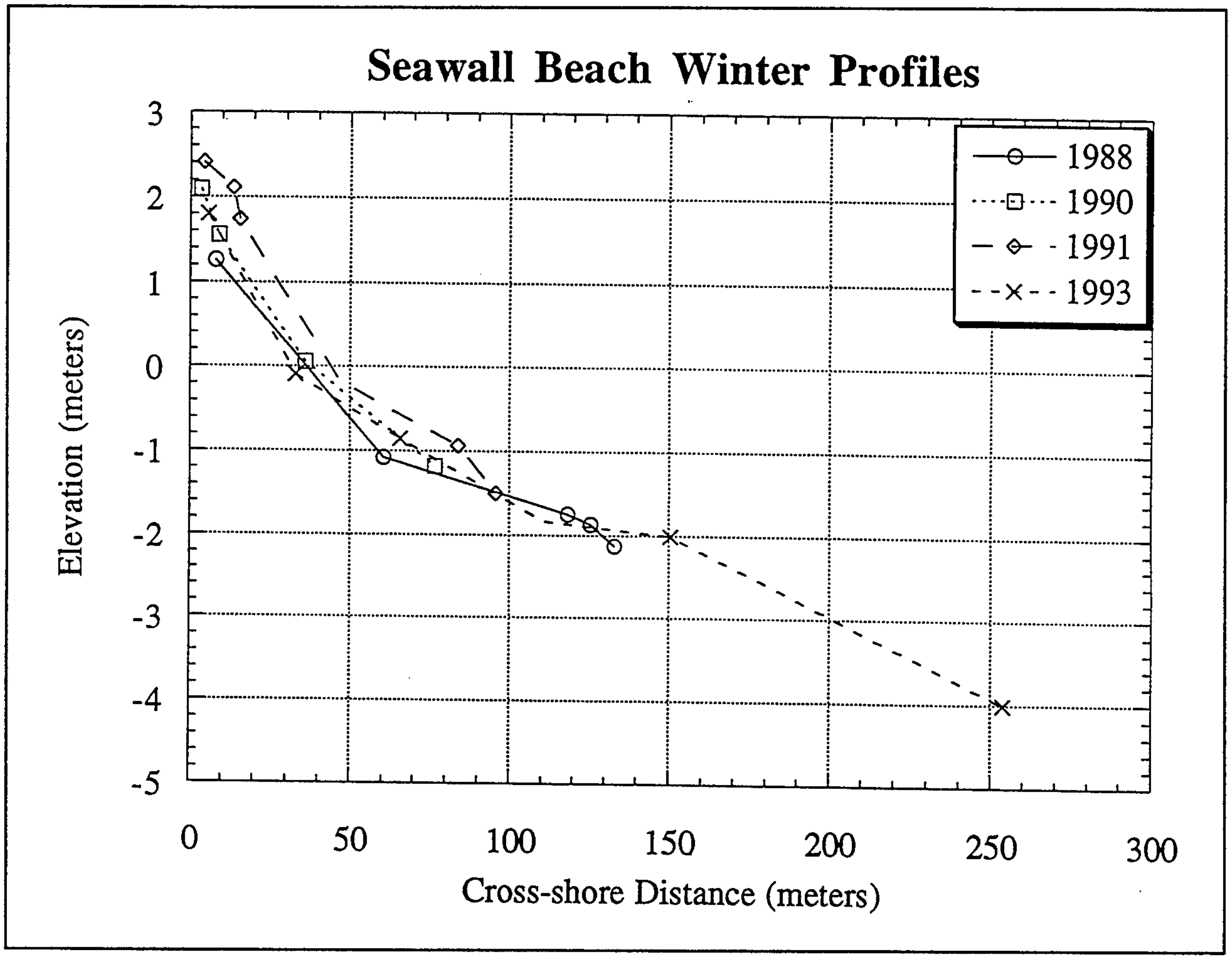


Figure 8. Winter profiles for line 13 on seawall beach between 1987 and 1993

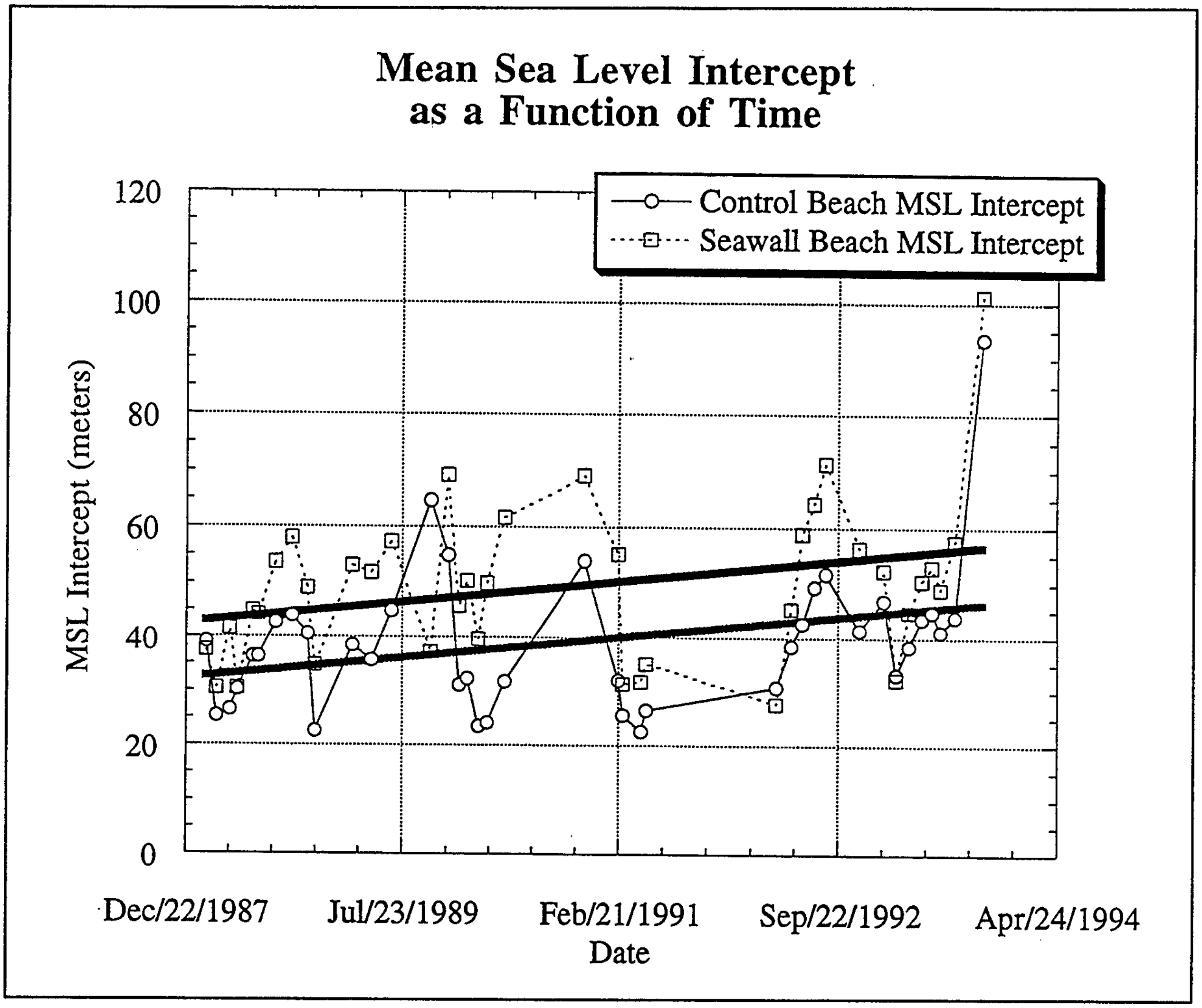


Figure 9. Change in location of mean sea level intercept (beach width) for seawall and control beach from 1988 to 1993 at Aptos Seascape

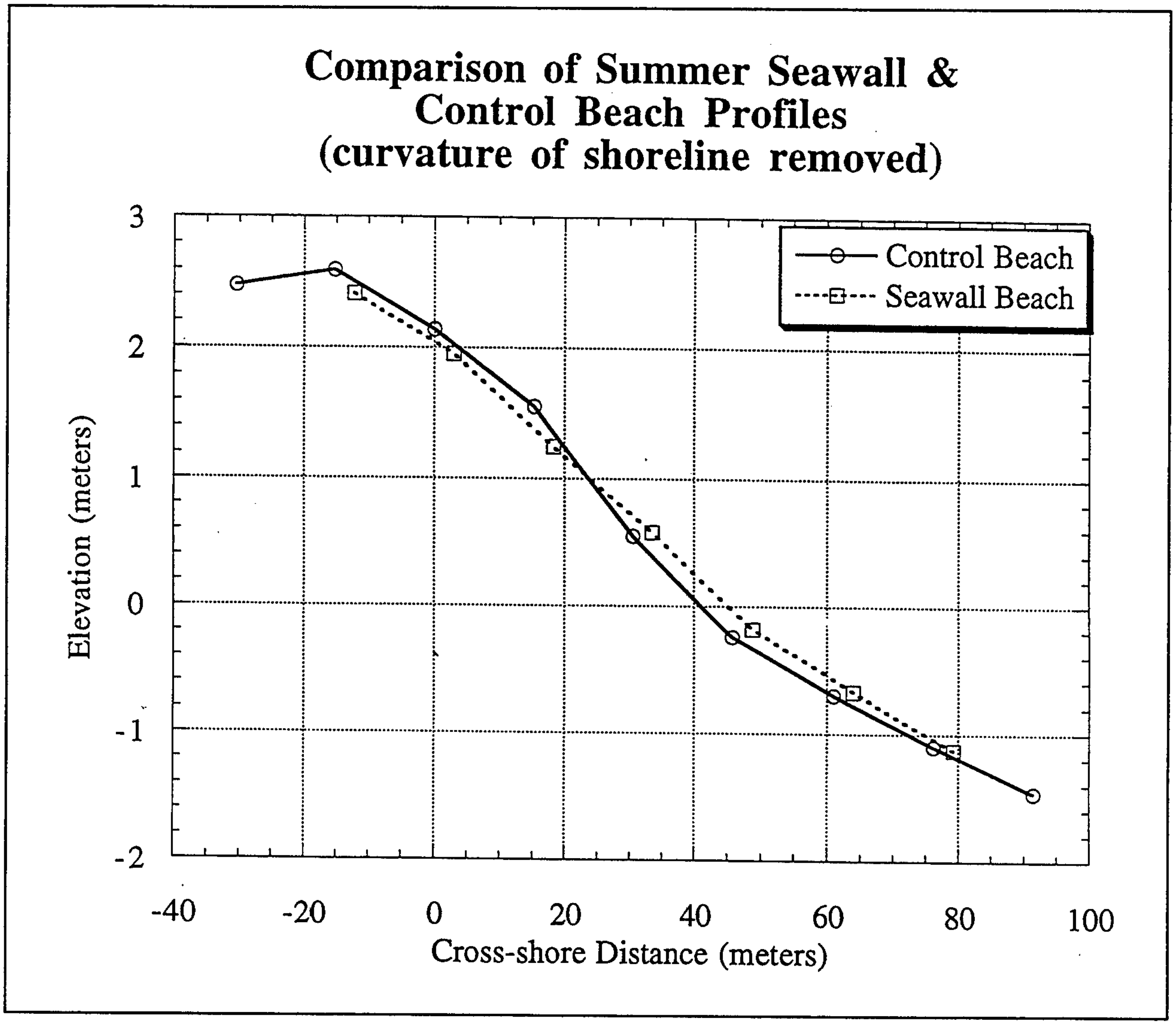


Figure 10. Comparison of averaged summer profiles (June) from seawall-backed and control beach (profile lines 13 and 18). See Figures 7 and 8 for years included

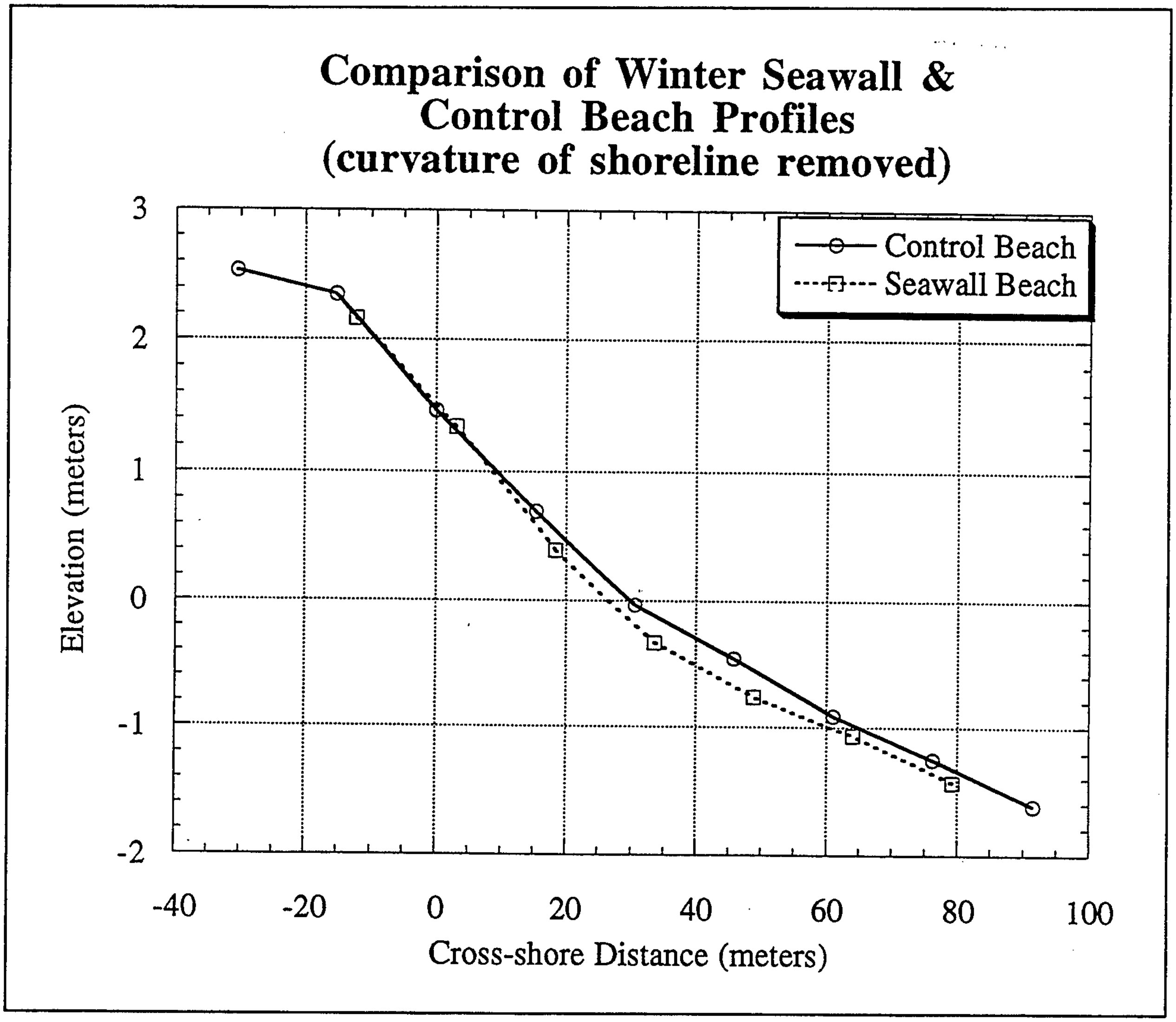


Figure 11. Comparison of averaged winter profiles (February) from seawall-backed and control beach (profile lines 13 and 18). See Figures 9 and 10 for years included

3 Effects of the Storm Waves of 1995 on the Seawall-Backed and Control Beaches

Introduction

The storms of January 1995 produced some of the most severe beach erosion along the coast of California in a decade. The last major episode of severe widespread shoreline erosion took place during the winter of 1983 when the entire coast of California was battered by 3 months of storm waves accompanied by elevated sea level and high rainfall due to a major El Niño event. The California coast suffered over $100 million in storm damage during that winter. Damage during the 1995 storms was relatively minor, but the beach changes were dramatic.

While the authors' findings in Chapters 1 and 2 were consistent from year to year, questions remained concerning the effects of the seawall during a period of major storm waves. The storms of 1995 provided an opportunity to study (a) the behavior of the seawall-backed beach compared with the control beaches during storm conditions (as evidenced by surveys immediately following a storm), and (b) study the recovery of the seawall-backed beach compared with the recovery of the control beaches.

Typical Non-Storm Conditions

Monterey Bay typically has moderate wave and tidal conditions with tidal heights, measured at Monterey, ranging from lows of approximately -0.52 m mean lower low water (mllw) (0.32 m msl) to highs of +2.19 m mllw (3.04 m msl). Average tidal stage is approximately +0.9 m mllw (1.75 m msl). Because inner northern Monterey Bay is sheltered from the dominant northwest swell, significant wave heights measured at the Santa Cruz Harbor wave gauge are considerably less than the offshore values and range from a low of 0.25 m to a maximum of nearly 3 m, with an average of less than 1 m.

Storms of 1995

The winter of 1994-95 brought with it the largest waves recorded since the Santa Cruz gauge was installed 17 years ago, but the winter did not produce any significant high tides (Figure 12). The first storm of the winter arrived on December 31, 1994, and produced sustained wave heights greater than 1 m for nearly 17 days. During this storm, on January 6, the significant wave heights grew to exceed 1.50 m for the next 6 days, with peaks as high as 3.26 m. The largest wave heights of the season, and in the entire wave record for the Santa Cruz Harbor gauge, occurred on January 22, 1995, when a significant wave height of 3.32 m was recorded.

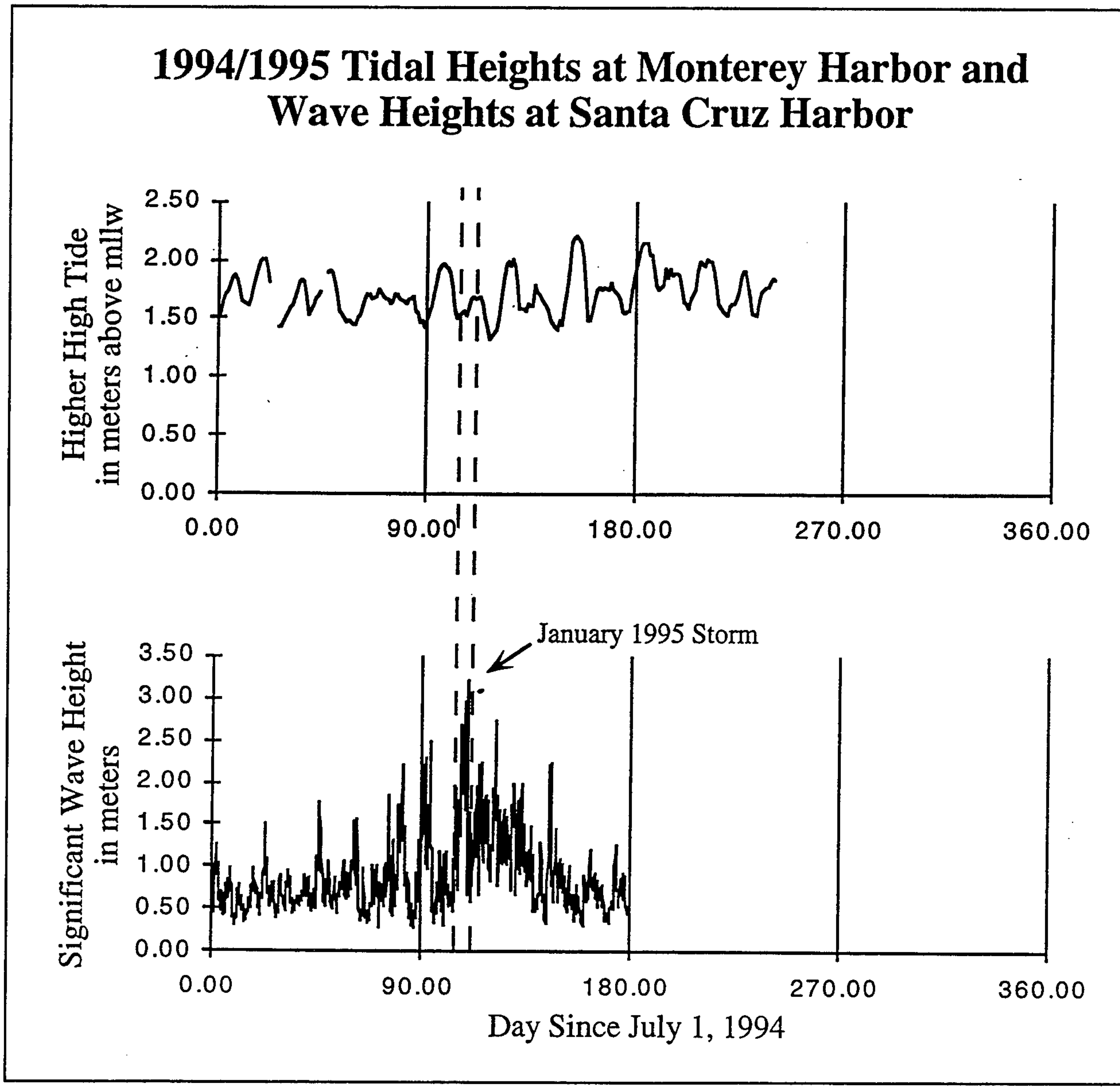


Figure 12. Wave and tidal heights, 1994-95, Monterey Bay

Beach response to the storms of January 1995

Profiles. At the Aptos Seascape seawall study site, the primary beach responses to the storms of 1995 were a rapid change in profile shape, a significant decrease in beach elevation due to frontal scour, and erosion of approximately 115 m^3 of sand for every alongshore meter of beach. Several indicators of substantial beach elevation change were apparent to observers familiar with the study site. For example, the stairs on the northern flank of the seawall, usually buried in the beach, were completely exposed as the beach eroded (Figure 13). In addition, the access stairs fronting the seawall, which usually extend below sand level, were left dangling meters above the newly scoured beach (Figure 14).

Figure 13. Stairs at north end of Aptos Seascape seawall after the storms of January 1995

These extreme changes in beach level were reminiscent of the changes associated with the 1983 winter storms. However, despite obvious erosion, photographic comparison of the north control beach after the 1983 and 1995 events reveals that sand loss in 1995 (Figure 15b) was significantly less than it was in 1983 (Figure 15a).

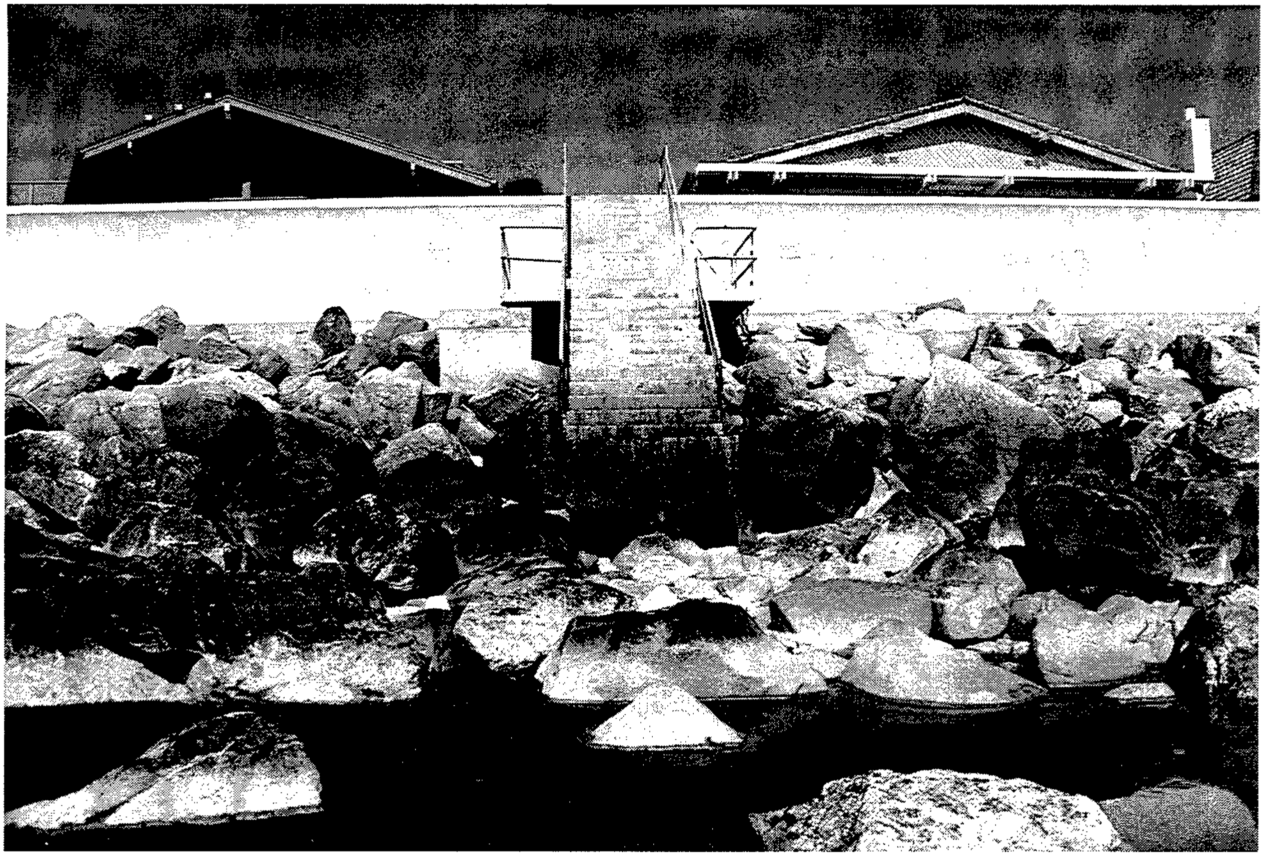


Figure 14. Stairs fronting Aptos Seascape seawall after the storms of January 1995

In order to quantify beach response and recovery, monthly, and when possible, biweekly surveys were conducted. Spatially averaged survey profiles indicate that the north control, seawall, and south control beaches responded almost identically to the storm waves of 1995 (Figures 16 and 17). All three beach profiles changed from an upwardly concave beach with a steep face and a fairly wide berm (wider for the control beaches because their landward extent is not limited by the seawall) to a flatter, intertidal beach face typical of post-storm profiles. In addition, while the seawall beach displayed a slightly greater change in elevation directly in front of the wall (Figure 18), the remainder of the seawall beach and the control beaches displayed comparable changes in elevation ranging from -0.5 to -2.2 m depending on cross-shore location. The average elevation change for all these beaches was approximately -1.5 m, with the greatest elevation change occurring between 15 and 30 m seaward of the baseline (the seawall).

Beach width. In addition to changes in beach profile, the cross-shore location of the mean sea level (msl) intercept moved landward, indicating a significant decrease in beach width (Figure 18). The msl intercept migrated an average of 41 m landward between December 10, 1994, and January 17, 1995. Before the first December storm, the msl intercept was at a fairly constant

a. 1983

b. 1995

Figure 15. Comparisons of beach scour at north end of Aptos Seascape seawall. Photo scales differ; the seawall was under construction in 1983 and the sewage manholes (tops indicated by arrows) have been protected by riprap. Despite these differences, photos demonstrate that relative to the top of the manholes, the beach was significantly lower in elevation after the 1983 storms as opposed to the 1995 storms

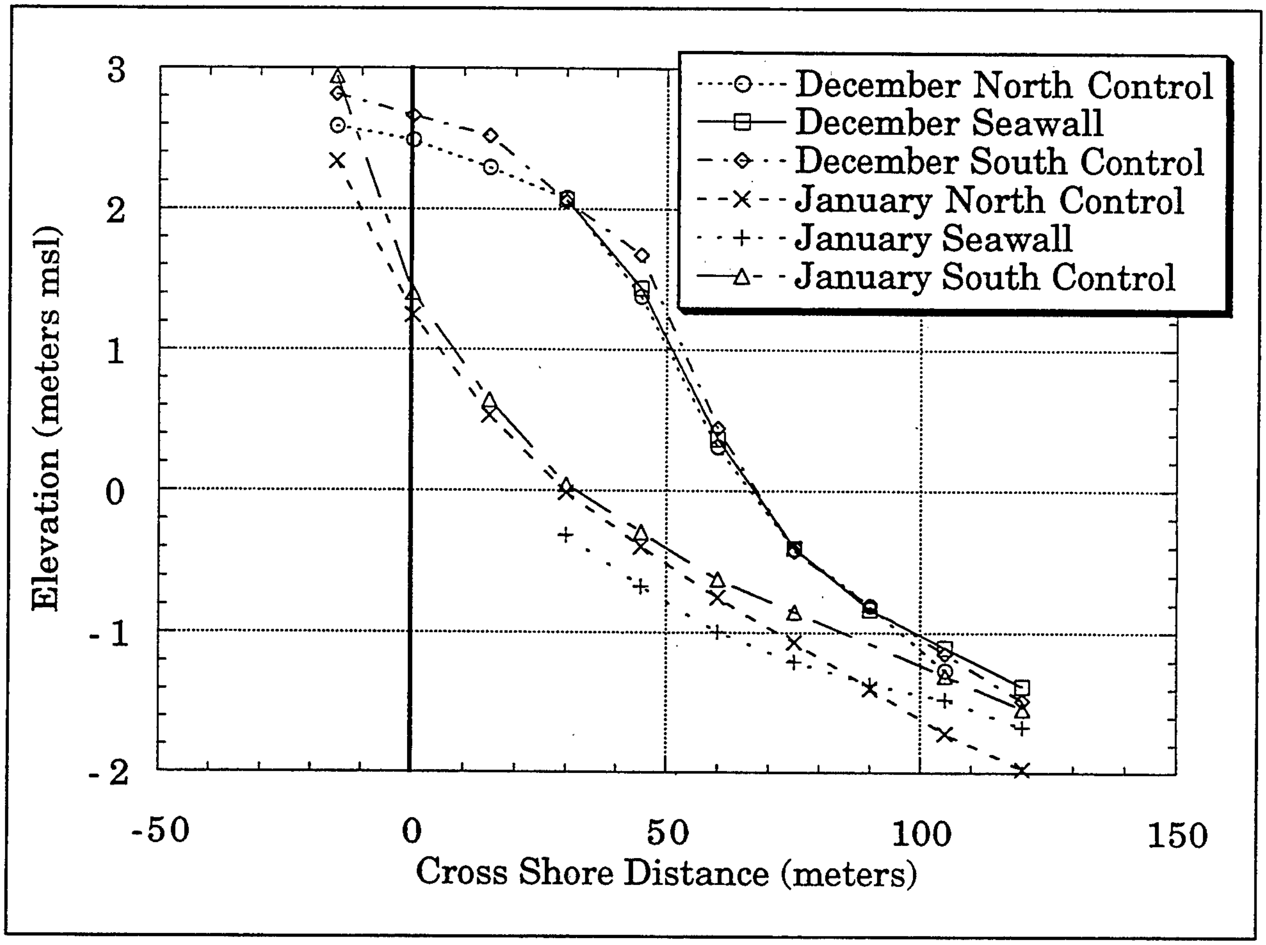
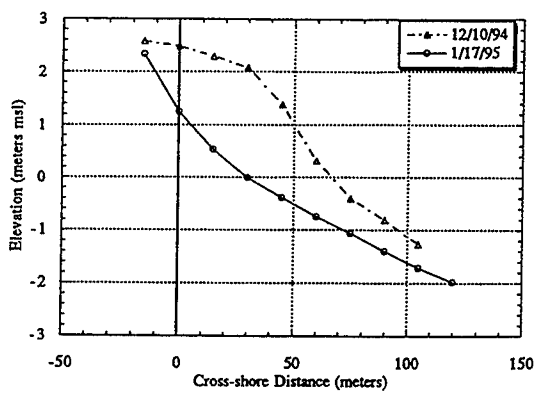


Figure 16. January and December average profiles of seawall and control beaches. The seawall runs alongshore at the zero baseline

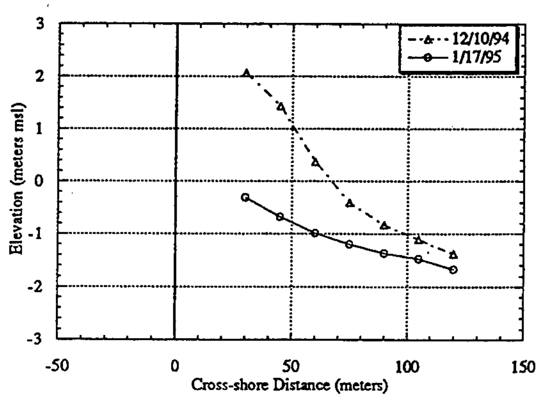
cross-shore location for all three beaches. After the storms, however, the mean sea level intercept for the beach directly fronting the seawall had migrated landward an average of 12 m further than the intercept for the control beaches. This difference in beach width between the seawall and control beaches appears to be due to increased scour directly in front of the seawall.

Scour depth and magnitude. The depth of scour in front of the seawall during the storms of 1995 has been ascertained by plotting the elevation of the beach directly fronting the wall. This elevation, plotted for line 13 at the center of the wall, is representative of the changes that occurred along the remainder of the seawall (Figure 19).

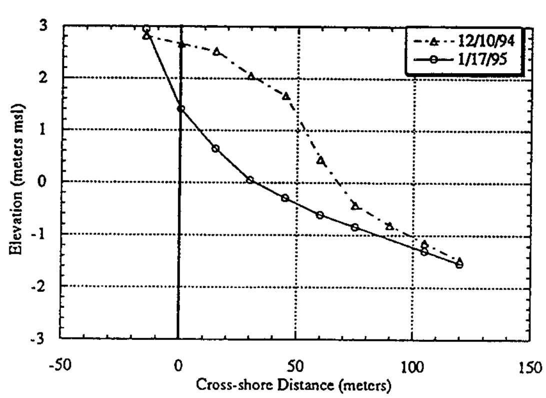
Scour depth during January 1995 reached an elevation of 0.4 m below msl. A scour depth of 0.2 m below msl was reached in 1987; however, it is the magnitude of scour, or net change in beach elevation between surveys, which distinguishes these two winters (Figure 20). The most significant change during the monitoring period was the -2.2-m change that occurred from December 1994 to January 1995.



a. North control beach



b. Seawall beach



c. South control beach

Figure 17. Average beach profiles for north control beach (a), seawall beach (b), and south control beach (c), before and after January 1995 storms. The seawall runs alongshore at the zero baseline

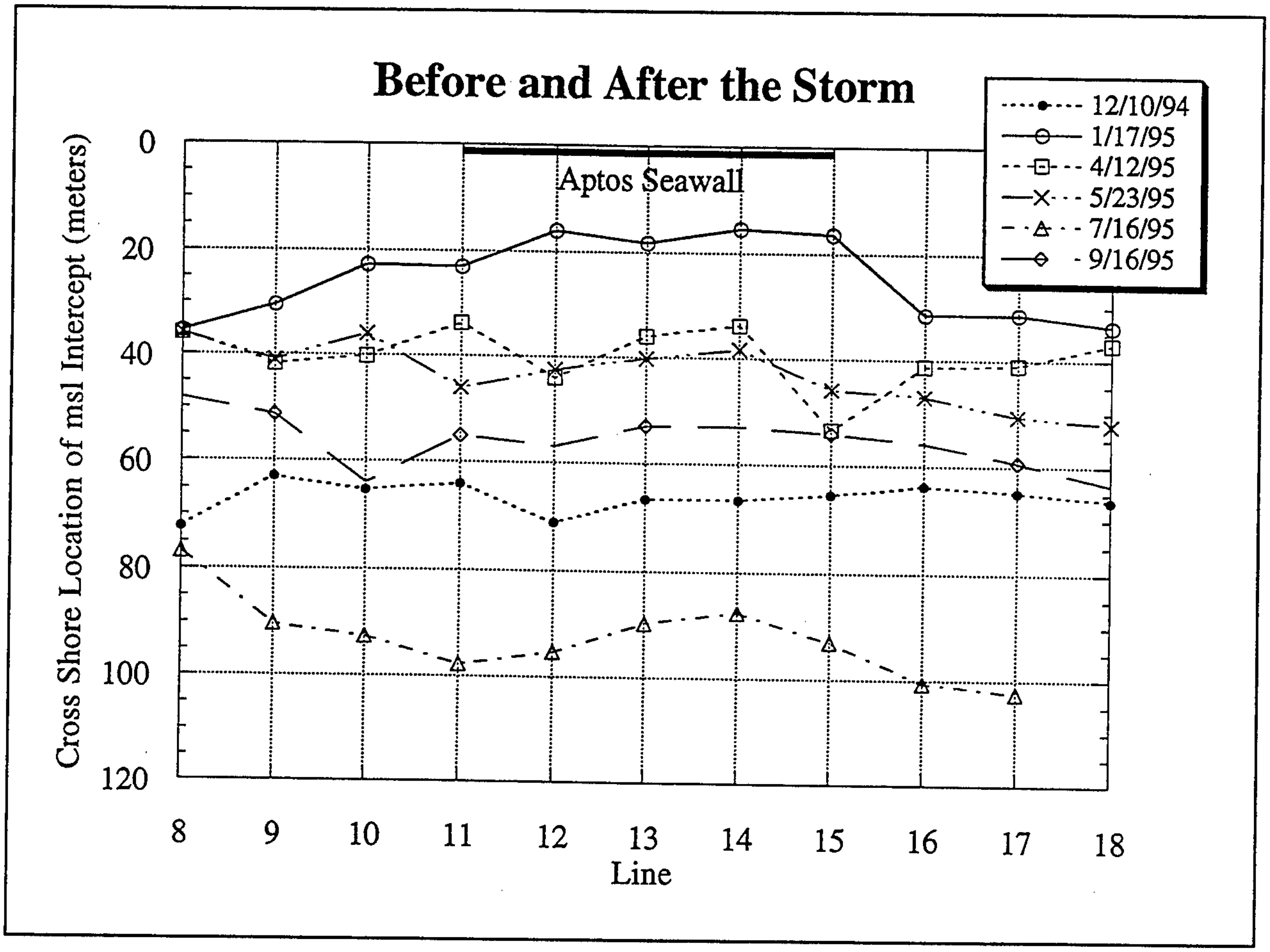


Figure 18. Alongshore differences in beach width before and after January 1995 storm

Changes in 1995 Compared to Previous Winters

Throughout the long-term monitoring period, Griggs, Tait, and Corona (1994) found only small variations in the shape and elevation of the February profiles for both control and seawall beaches (February profiles are used to represent the typical mature winter profile for the area, see Chapters 1 and 2). Thus, the beach changes resulting from the winter of 1995 represent the most significant changes caused by winter storm activity that have occurred during the monitoring period.

During the winter of 1986, the first winter of long-term monitoring, Griggs and Tait (1988) reported crescentic-shaped end scour on the south control beach. Interestingly, despite the strong wave action of the January 1995 storms, no such scour was observed. Accelerated frontal scour and thus a significant decrease in beach elevation did occur, however. Throughout the monitoring period a minimum beach elevation of +1.4 m (msl) was observed under typical conditions. During the storms of 1995, frontal scour lowered

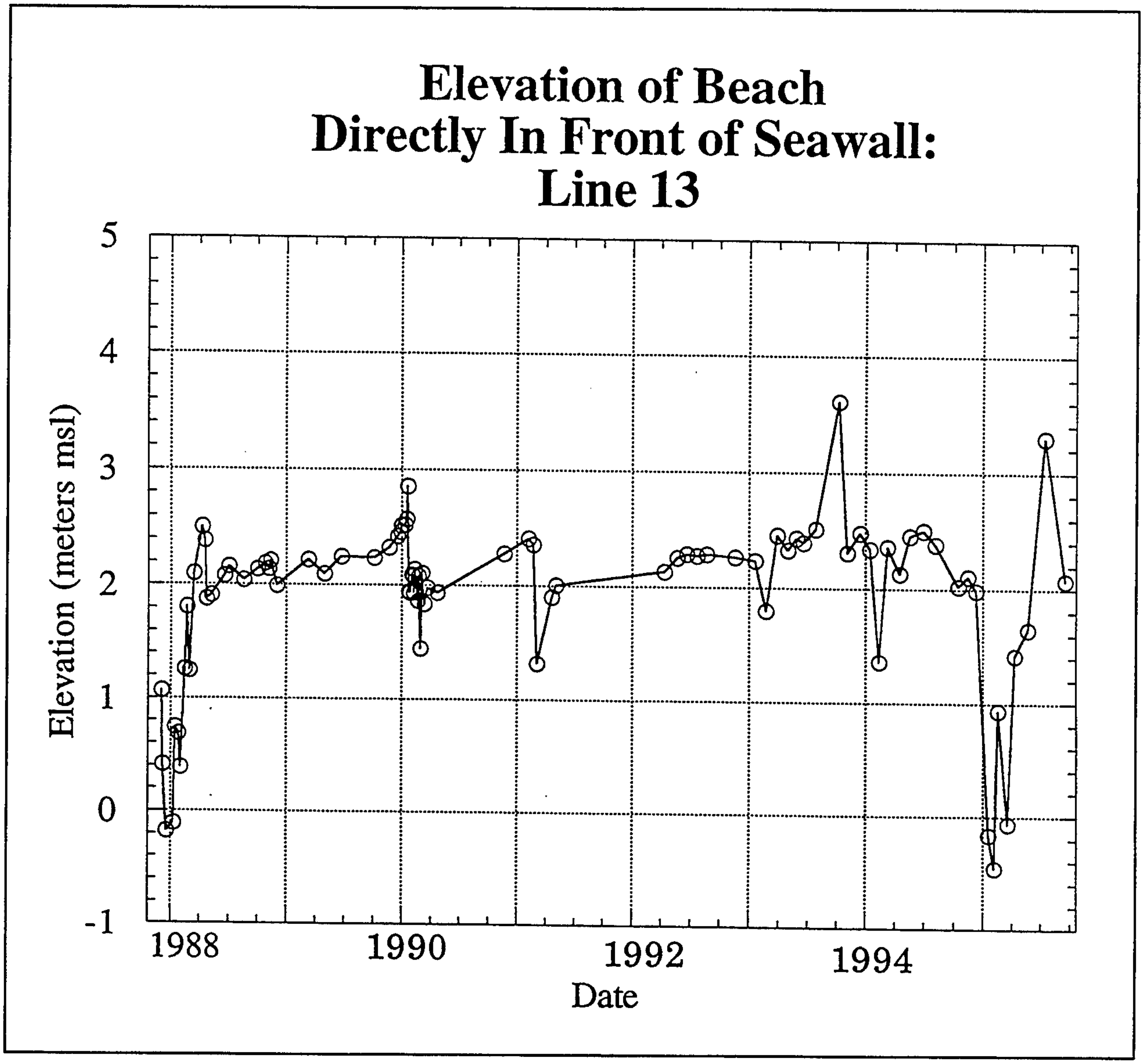
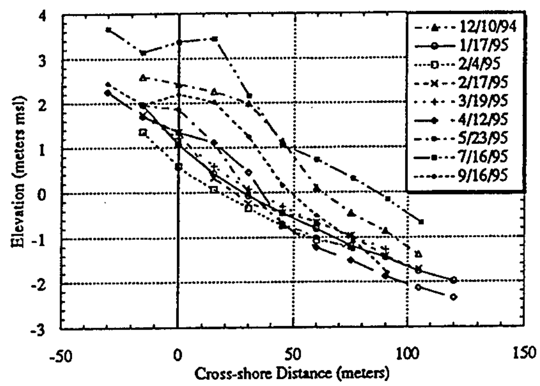


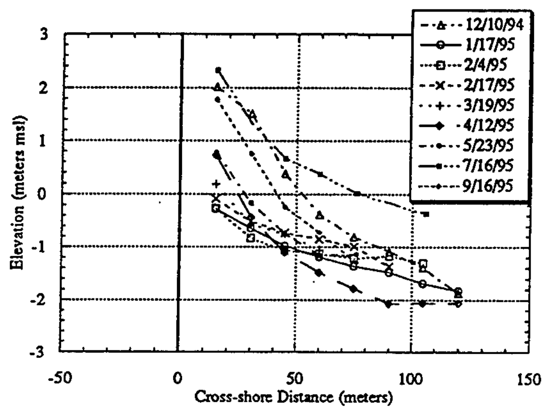
Figure 19. Elevation of beach directly in front of the Aptos Seascape seawall between 1987 and 1995

the beach to -0.5 m (msl). Although this elevation was nearly reached during the winter of 1987, the total scour between surveys at that time was much less significant (Figure 21). The change in beach elevation for January 1995 was -2.2 m, while the changes in January 1988 never exceeded -0.7 m.

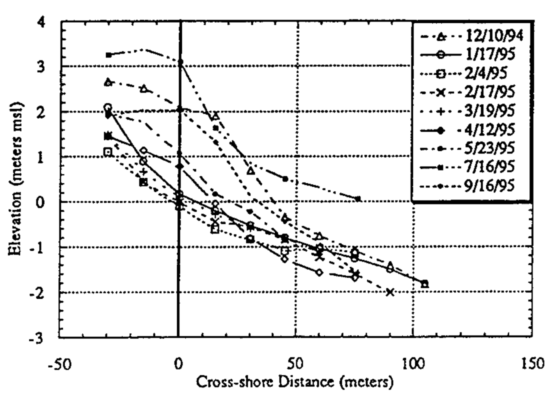
In summary, the January 1995 storms significantly lowered all three beaches, produced the greatest scour depth, and generated the greatest changes in winter profile shape, beach elevation, and beach width since the long-term monitoring program began in 1986. Although these changes were significant, they were not nearly as extreme as the changes of 1983, which overtopped and



a. North control beach



b. Seawall beach



c. South control beach

Figure 20. Beach recovery: Average profiles of a), north control beach, b) seawall beach, and c) south control beach from December 1994 to September 1995. The seawall runs alongshore at the zero baseline

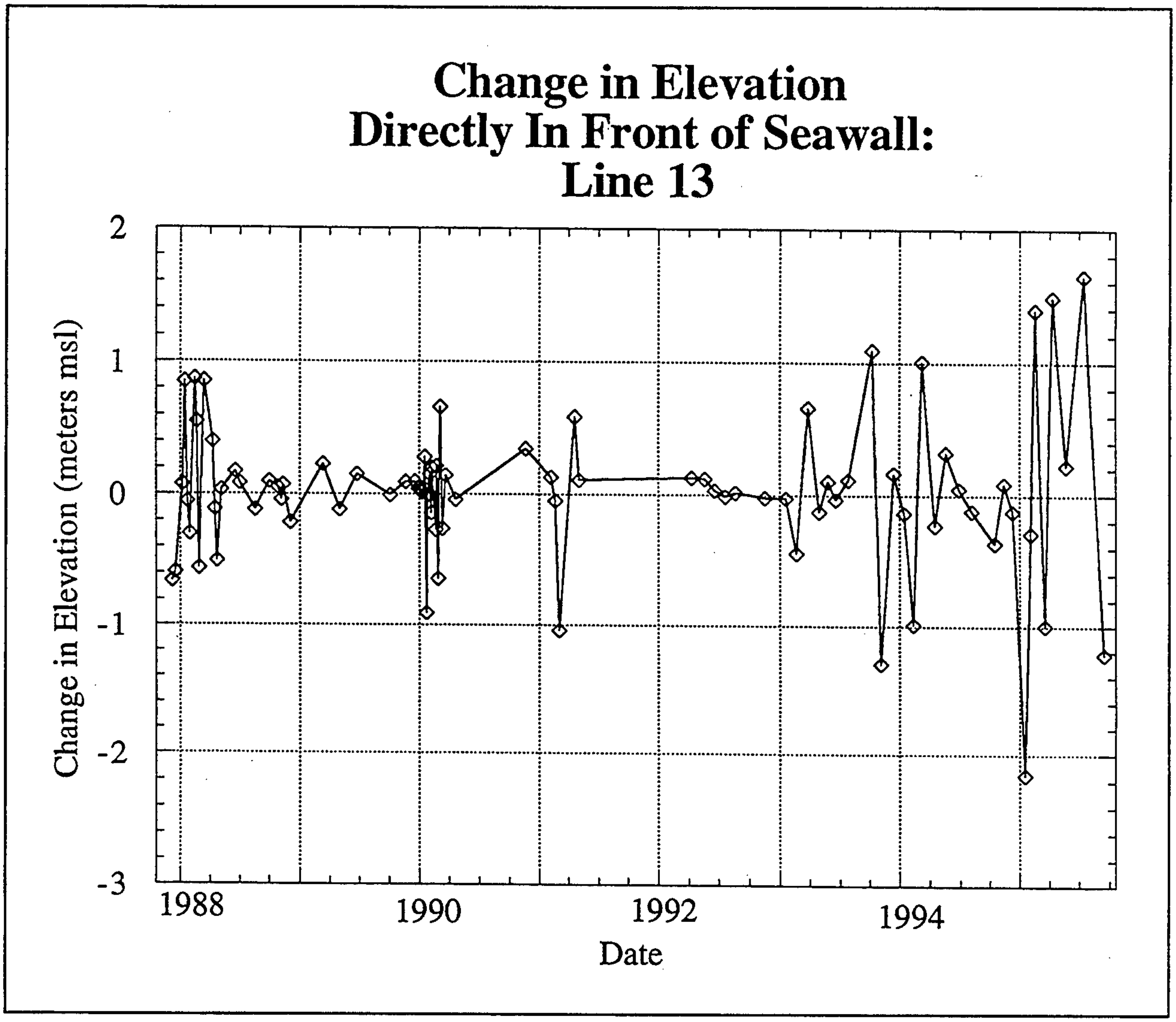


Figure 21. Change in elevation of beach directly in front of Aptos Seascape seawall between surveys 1986-1995

undermined the existing revetment, leaving it in ruins, and prompting the construction of the large concrete seawall that has been monitored.

Previous published results (e.g., Griggs and Tait (1988)) indicate that frontal and end scour during early winter storms can produce intensified erosion in the vicinity of a seawall. The storm of 1995 produced enhanced frontal erosion, but did not produce end scour on the south control beach as noted in 1988. Some end scour may have occurred on line 10 (Figure 18), but it does not appear to be significant. Lines 12, 13, 14, and 15 in front of the seawall all experienced an approximate 12-m shoreward shift of the msl intercept relative to the lines on the control beaches (8,9,10 for the north control beach and 16,17,18,19 for the south control beach). In general, the msl intercept was

translated 40 m shoreward during the period from December 10, 1994, through January 17, 1995.

Beach Recovery After 1995 Storms

After the initial January storm, which caused the most drastic changes of the season, the Aptos Seascape beach profiles continued to lower slightly, as waves pounded at the newly created dissipative profile. This continued erosion is apparent in the profiles from the survey in early February (Figure 21). However, despite the significant changes in profile geometry, beach width, and scour depth that occurred during January and early February, the third post-storm survey taken in mid-February reveals that deposition had occurred, and that the seawall and control beaches had quickly begun to recover (Figure 21).

In early March, a second, less significant, storm struck Monterey Bay. According to a March 19, 1995, survey, little, if any, erosion was generated by this storm. In fact, by mid-March, minor deposition, accompanied by slight erosion further seaward, had occurred on the landward half of all three beaches. This pattern of deposition and erosion indicates that a reflective profile was redeveloping on the seawall and control beaches. By mid-April, only 3 months after the initial storm, reflective profiles, directly mimicking the profiles from December, had been reestablished, although at an elevation approximately 1-2 m lower. Beach elevation continued to rise such that by July 1995, profiles for all three beaches were higher than they were in December 1994.

Consistent with the fairly quick recovery of profile shape, and with slower increases in overall beach elevation, is a significant increase in beach width over much of the survey area by mid-April (Figure 18). By this time, the beach directly fronting the seawall had widened an average of approximately 20 m while the northernmost and southernmost ends of the Aptos Seascape beach had remained at nearly the same width as that established by the January storms. Despite this widening, which occurred by mid-April, the beach was still an average of 26 m narrower than it was in December 1994. By mid-July, however, the beach had widened significantly and in most locations it was at least 20 m seaward of its December position. The final survey, completed in mid-September, revealed that the beach had again narrowed landward of its December location. Several consecutive days of high energy waves with maximum significant heights of 0.8 m coincident with 1.5+ m (mllw) spring high tides on September 7-10, were responsible for this deflation in beach profile.

4 Conclusions

Although not as erosive as the El Niño storms of 1983, the waves of the 1994-1995 winter were the most intense during 8 years of beach monitoring in the vicinity of the Aptos Seascape seawall. Beach response was not as dramatic in 1995 as in 1983, but beach elevation was significantly lowered and the changes were great enough to provide significant insight regarding the response of a seawall-backed beach to storm conditions.

Similar responses of the control and seawall beaches to the storm waves of 1995 were consistent with long-term observations. In addition, the beach in front of the seawall quickly lost the imprint of accelerated scour and a general alongshore homogeneity began evolving within months of the 1995 storms. There is no evidence of impaired recovery and, if anything, initial recovery was more rapid on the seawall-backed beach. These results indicate that although beach width decreased in front of the seawall due to passive erosion, active erosion, even under storm conditions, was minimal and did not produce any long-term effects.

Construction of a seawall on a beach can have three different potential effects: impoundment, passive erosion, and active erosion. The first two effects are predictable and relatively straightforward. The latter appears to have been the source of much controversy and until recently had not been systematically investigated in the field. Seven years of beach monitoring at a seawall on the central coast of California have allowed the authors to (a) document the seasonal beach changes which take place in response to the presence of seawalls, and also (b) compare year-to-year changes to evaluate any long-term effects.

A number of consistent beach changes related to the seawalls have been recognized as a result of long-term monitoring. During the transition from summer to winter beach state, the berm is cut back preferentially in front of the seawalls relative to the adjacent unarmored beaches. Once the berm has retreated landward of the seawall, there are no significant differences between the beach profiles fronting the wall and those from the adjacent control beach. Repeated surveys and comparisons at both an impermeable vertical seawall and a sloping revetment indicate little consistent difference in profile response due to differences in permeability. Either the apparent differences in

permeability of the two structures are not significant to wave reflection, or the importance of reflected wave energy to beach scour needs reconsideration.

Scour was often observed at the downcoast end of each structure as a result of wave reflection from the end section of seawall. The extent of scour (which reached a maximum of 150 m downcoast) appears to be controlled by end-section or return wall orientation, the angle of wave approach, and wave height and period. Surveys of the spring and summer accretionary phase indicate that the berm advances seaward on the control beach until it reaches the seawall. At that point, a berm begins to form in front of the seawall and subsequent accretion occurs uniformly on both beaches. Thus, while the winter erosional phase is influenced to some degree by the presence of a seawall, this is not the case for the berm rebuilding phase.

Comparisons over the 7 years of monitoring indicate that the summer berm on both the seawall-backed beach and the control beach has built out progressively further each year. This is believed to be due to the direct or indirect effects of reduced storm wave activity (drought conditions) during most of this period. The winter profiles on seawall and control beaches, however, show little variation from year to year . Finally, of greatest significance, is the comparison of time-averaged winter and summer profiles for the seawall-backed and control beaches. Comparison reveals no distinguishable differences between the winter profile for the seawall and control beaches and the summer profile for the seawall and control beaches.

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13. ABSTRACT *(Maximum 200 words)*

Coastal protection structures have historically been the most common approach to dealing with the problem of shoreline erosion in the United States. Three potential impacts of these structures have been identified, and include: (a) impoundment or placement loss, (b) passive erosion, and (c) active erosion. The first two are relatively straightforward and predictable. The third has been the subject of considerable discussion and debate, but until recently, has not been systematically investigated in the field. This report presents the results of 7 years of biweekly to monthly monitoring of beaches adjacent to seawalls along the central California coast. These surveys have allowed evaluation of both the seasonal beach changes due to the presence of seawalls as well as any longer term effects. Although active erosion during winter months has been documented at seawalls in this study, erosion has been seasonal and temporary in nature. A comparison of summer and winter beach profiles on beaches with seawalls and on adjacent control beaches reveals no significant long-term effects or impacts of seawalls in this location during this 7-year period.

After 7 years of surveying, however, the question of how the seawall-backed beach would behave compared with the control beaches during a period of severe winter storms had still not been answered. During the eighth, and final, year of surveying an opportunity to answer this question was presented. In January and March of

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1995, two winter storms struck the central coast causing extensive flooding and beach erosion. This report includes the results of surveys from January to September 1995, and reveals that the behavior of the seawall beach during these storms was consistent with the conclusions reached after the previous 7 years of surveying this site.